Automated Reconstruction of Endoscopic Images of the Esophagus

Albert Shar[1], Mark Weiner[2], Richard Kim[3], James Reynolds[3]

[1]University of Pennsylvania School of Medicine, [2]Hospital of the University of Pennsylvania, [3]University of Pittsburgh School of Medicine

ABSTRACT

Endoscopic devices distort the image of a region under examination. Previous work has shown that there are computational methods which can precisely reconstruct planar structures in a model of the esophagus and that reconstruction in human subjects is operator independent. The purpose of this report is to show that much of the process can be automated and to provide additional evidence that the reconstruction is both accurate and reproducible.

INTRODUCTION

The current inability to precisely quantitate the extent of esophageal involvement by Barrett's Metaplasia precludes an accurate assessment of the natural history of the disease. Patients with Barrett's Metaplasia are predisposed to developing adenocarcinoma. Precise measuring techniques would allow chronological assessment of abnormal mucosa by a variety of clinical, pathologic and molecular techniques, in addition to measurement of the response to treatment. Because the number of cells in Barrett's tissue at risk for malignant transformation can be estimated as a function of the extent of mucosa involved[1,2] and because Barrett's esophogus commonly presents as an irregular border, a nonlinear measurement of the area of involvement is necessary for accurate measurement. In an earlier report[3] a computer program was presented which was an attempt to address this problem. Evidence has been provided[4,5,6] that such measurement was possible. Other research[7,8,9] has focused on related problems. However in one case[7] it was an attempt to address the distortion caused by the nature of the imaging lens and the other[8] required more expensive stereoscopic imaging systems. The final citation[9] of this group showed that the computer was significantly better than even an experienced clinician at estimating the size of a flat object in the stomach. Dealing with both an irregularly shaped lesion and the anatomical difference between viewing a locally flat surface of the stomach and the essentially cylindrical esophogus changes the nature of both the problem and possible solution.

Briefly, the methodology is based upon viewing a section of the esophagus and modeling it as a section of a cylinder. If endoscopic imaging produced a linear transformation of the esophagus to a flat photograph the entire from the "anatomical" section to the endoscopic image to a dissection of the transformed image could be graphically described as follows:

| 1. Endoscopic model | 2. Image | 3."Unrolled" reconstruction |
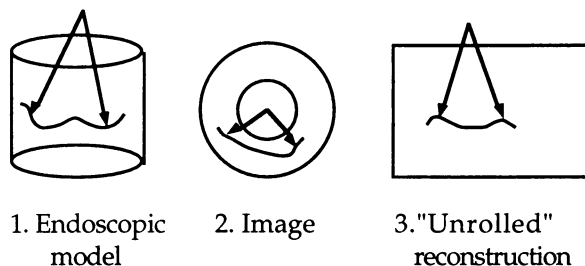
It is not difficult to see that the transformation from 2. to 3. is one between rectangular and polar coordinates and that transformation can be expressed precisely as:.
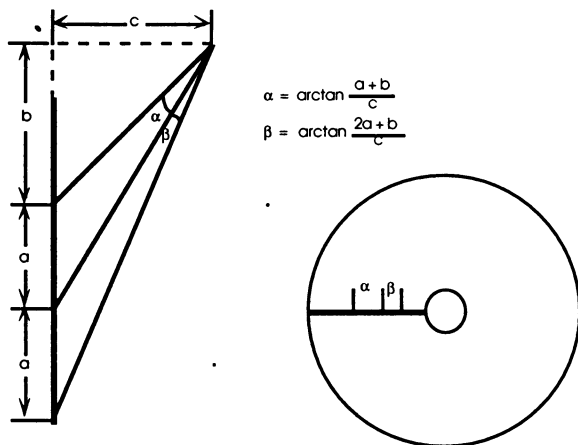
$$(x,y) \rightarrow (\arctan\frac{x}{r}, r) \text{ where } r = \sqrt{x^2+y^2}$$
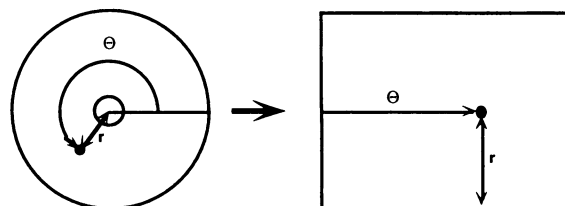
1. Polar Coordinates 2. Rectangular Coordinates

Since equal distances on any radius in the image view do not represent equal distances in the

esophagus this transformation would not provide an accurate measurement of vertical distances. However, mathematically this could be solved using the following figure.

$$\alpha = \arctan \frac{a+b}{c}$$

$$\beta = \arctan \frac{2a+b}{c}$$

Equal vertical distances in the esophagus versus how they appear in the image view.

The reality of the situation is slightly more complex. The images are not perfect circles, so that calculating the center is a nontrivial task. In addition the actual vertical scale needs to be calibrated to take into account distortion from the lens of the camera. The former can be accomplished using "best fit" techniques and the latter accomplished by recording the image of a 1 cm grid and reverse scaling.

Measures of the validity of the process are described in earlier works[4,5,6]. Briefly they show that calculating the affected area using the computer reconstruction is highly correlated with similar direct measurements of a constructed model and that measurements by two endoscopists on the same human subject were also highly correlated.

PROCESS AUTOMATION

The process of taking an endoscopic image and producing a full reconstruction can be viewed as consisting of a number of steps:

1. Image acquisition
2. Image digitization
3. Establishing image boundaries
4. Image transformation
5. Image completion

6. Stacking of multiple transformations

The first two steps can be efficiently performed by the endoscopist, adding little to the overall duration of the endoscopy procedure. Whereas endoscopy photographs often tend to place the lesion of interest in the center of the image, our transformation algorithms require that the center of the image be focused on the distal portion of the visible esophagus. Once the proper orientation is confirmed, most endoscopy hardware allows a snapshot of the image to be stored digitally. Usually, a series of photographs is stored in this manner as the endocope is withdrawn, each representing a view of the esophagus from a different distance. For the purpose of image stacking, this distance must be recorded at the time the image is stored.

The purpose of the computer is to take the series of images and apply steps 3 through 6. Image boundaries can be defined by the user who can manually define a locus of points at the perceived image boundary. A best fit circle can then be applied to the points, or alternatively, it is possible for the computer to automatically define a border based upon contrast differences between the image and the surrounding pixels.

Once the image boundaries are defined, the pixels are effectively splayed according the formula described above. As this step involves applying a transcendental function to each individual pixel, it is the rate limiting step. However, with the use of a math coprocessor, a standard sized 120 x 120 pixel image can be converted in a matter of 3 seconds on a Quadra 950.

The process of image transformation separates adjacent pixels, but does not automatically fill in the gaps. As a result, the "raw" transformation contains too much white space to be appropriate for identifying lesions. An intermediate step is required which replaces each white pixel with an appropriate image color. Ideally, a continuous range of colors could be used to fill the white space. However, since images are stored with a 256 Color Table (from a palette of millions) a complete spectrum is not possible. Instead, each white pixel is replaced
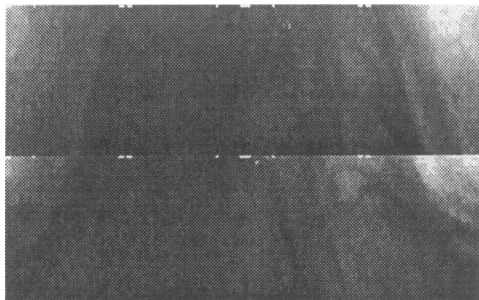
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with the same color of the first non-white pixel above it. The resulting image is a computer enhanced reconstruction of an unrolled segment of the esophagus.

CONCLUSIONS AND DIRECTIONS

The following images are the result of applying the program on a human with Barrett's metaplasia.
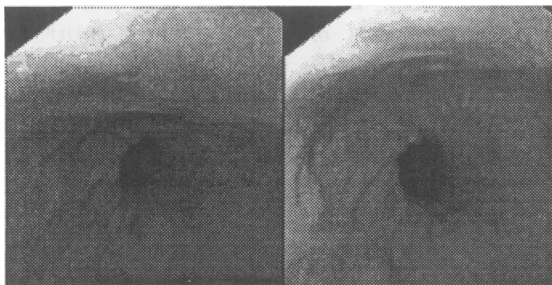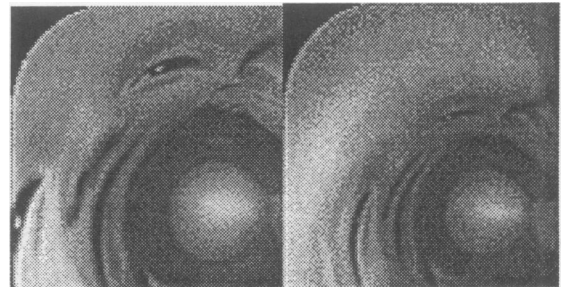

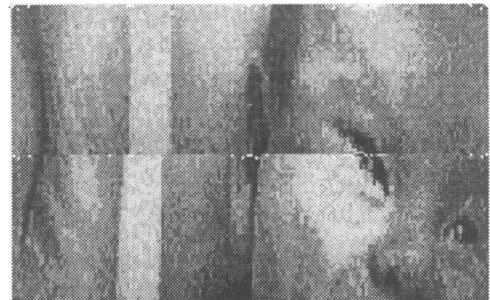Two esophogeal images taked 2 cm apart

Unrolled and stacked image

In order to more vividly demonstrate both the stacking methodology and the accuracy of the reconstruction, a photograph was rolled and inserted into a tube which was the imaged using a Pentax endoscope. It was then subjected to the entire automated process.

Two images taked 2 cm apart

Unrolled and stacked image

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